CONSTRUCTING THE DENSITY PREDICTIVE MODELS WITHIN THE RAMP JUNCTION AREAS ON URBAN FREEWAY
-BASED ON THE 1ST URBAN FREEWAY IN BUSAN CITY-

Mi-Hyeon KWON, Tae-Gon KIM, Yu-Na JUNG
Division of Civil and Environmental Engineering
Korea Maritime University
Busan, Korea
a28209@nate.com

ABSTRACT

Urban freeway is a primary arterial in a big city, which is connected between the urban area and the suburban area or circulated along the circumference of the suburban area. However, most of the urban freeways in Korea do not play their roles in the urban transportation system, because they are experiencing severe traffic congestion with the incoming or outgoing traffic volumes in the ramp junction areas regardless of the rush hours.
Additionally the design criteria of the expressway cannot be applied to the urban freeway for identifying the travel patterns on the urban freeway, because the travel patterns on the urban freeway are different from those on the expressway. So it is very strongly needed to suggest the appropriate density models with the identification of the roadway and traffic characteristics in the ramp junction areas on the urban freeway.
Thus this study is to collect the roadway and traffic characteristic data in the ramp junction areas on the urban freeway, analyze the roadway and traffic characteristic data in the ramp junction areas on the urban freeway, compare the relationship between the road and traffic characteristics in the ramp junction areas on the urban freeway, and finally construct the optimal density predictive models in the ramp junction areas on the urban freeway.
Also, the density predictive models in this study are compared with those suggested on the US highway capacity manual (HCM) and Korea highway capacity manual (KHCM). Based on the roadway and traffic characteristic analyses, and density model construction and verification in the ramp junction areas on the urban freeway, the density models by the KHCM and HCM are found not to fit for predicting the density characteristics on the urban freeway.

1. INTRODUCTION

1.1 Background

Urban freeway means a high-speed roadway keeping the free flow speed and carrying tremendous traffic flow rapidly except for the rush hours, as one of the primary arterials in the urban transportation system. However, urban freeway is not a high-speed roadway any more in the big city, because most of the vehicles use the urban freeway, and urban freeway is also jammed with the incoming vehicles regardless of the rush hours. What is worse, it is almost impossible to construct the new transportation facilities whenever new travel demand occurs, because a new budget must be made for expanding the new transportation facilities and the new transportation facilities must be coincident with the priority order of the facilities planned. Thus it is absolutely needed to increase the efficiency of the existing urban freeway instead of constructing the new urban freeway.

1.2 Objective

Urban freeway, which accommodates almost the free flow speed under the prevailing roadway and traffic conditions except for the rush hours, is composed of mainline segment, weaving segment, ramp and ramp junction like an expressway. However, there is a considerable difference in speed limit, grade, width, and length between urban freeway and expressway due to the land use limited, because urban freeway is located in the urban area, but expressway is located in the rural area. Additionally, there are the clearer congestion and non-congestion sections, the higher travel demand, and the shorter travel length in urban freeway than in the expressway. Until now, a study has been hardly made for urban freeway, despite the marked differences between urban freeway and expressway in Korea. Thus, the purpose in this study is to develop the density predictive model (DPM) based on the traffic and geometric characteristic data in the urban freeway ramp influence areas,

compare the density predictive model developed with the ones in the US highway capacity manual (HCM) and Korean highway capacity manual (KHCM), and finally suggest the improved density predictive model appropriate for the urban freeway ramp influence areas.

1.3 Literature Review

According to the US highway capacity manual (HCM, 2000), the level of service (LOS) in ramp influence areas is determined by density for all cases of stable operation, represented by LOS A through E. LOS F exists when the total flow departing from the merge area exceeds the capacity of downstream freeway segment. No density will be predicted for such cases. [1]

According to the Korean highway capacity manual (KHCM, 2005), the LOS criteria follow those in the US highway capacity manual (HCM, 2000), and the LOS criteria for ramp influence areas are shown in Table 1. Especially, density in the ramp influence area is predicted from the converted passenger cars using the traffic flow data collected in the field. [5]

Table 1. LOS criteria for merge and diverge areas

LOS	Density (pc/km/ln)
A	≤6
B	>6-12
C	>12-17
D	>17-22
E	>22
F	Demand exceed capacity

1.4 Data Collection

Specifically, urban freeway under the study is a divided and elevated highway having 2 lanes in each direction, and also has 7 off-ramps, 7 on-ramps, and 5 tunnels. The geometry and equipments were as shown in Figure 1.The speed limits are 80km/h on the mainline section and 50km/h on the ramp section, and the speed surveillance cameras are also installed on the mainline section in order to control the speedup of the vehicles (see Table 2). So, data collection was conducted in the ramp influence areas (Munhyeon (A), Daeyeon (B), Mangmi (C), and Wondong (D)) selected for the analyses of the roadway and traffic characteristics during April through June, 2008. And a master dataset was generated every 15 minutes by the detectors (NC-97) which were installed at the upstream, downstream and ramp locations in the merge and diverge influence area of urban freeway. It was converted into a data format for visual and statistical inspection via a spread sheet, and used for analyses. Occasionally the detectors produced bad data, and only valid data for all 24 hours were used in the analyses.

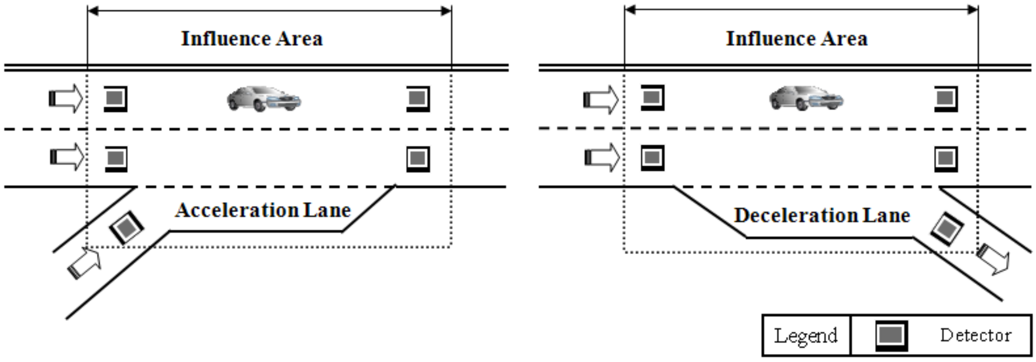


Figure 1. Urban freeway under the study, ramp geometries and detector locations

Table 2. Geometric characteristics in the merge and diverge influence areas

Ramp junction	A	B	C	D
Length of deceleration (m)	80	170	150	120
Length of acceleration (m)	130	230	120	230
No. of lanes (Mainline /Ramp)	2 / 1			
Lane width (m) (Mainline /Ramp)	3.7 / 3.7~5.0			
Speed limits (km/h), (Mainline /Ramp)	80 / 50			
Free flow speed (km/h), (Mainline /Ramp)	60 / 50			

2. Analysis of Traffic Characteristics

For the microscopic analyses of the traffic characteristics, flow was converted into the flow rate (pc/h) using the heavy vehicle factor, speed was converted into the space mean speed by the speed data of the detectors installed on the merge and diverge influence area, and density was also estimated by the reciprocal of the headway distance, which was the headway time multiplied by the space mean speed in the above.

2.1 Flow Rate

Flow rate was expressed by a vehicle per 15 minutes (pc/15min.), as a number of vehicles which passed the detector (NC-97) for a unit period, and converted into the hourly volume as shown in the below.

$$V_t = \frac{N}{T \times f_{HV} \times PHF}$$

$$V = \sum_{i=1}^{4} V_i$$

Where,

N	: No. of vehicles passed the detector
T	: Unit period (15 minutes)
f_{HV}	: Adjustment factor for heavy vehicle $(1/[1+P_{T1}(E_{T1}-1)+P_{T2}(E_{T2}-1)])$
PHF	: Peak hour factor
V	: Hourly volume (pc/h)
V_i	: Volume for 15 minutes (pc/15 min.)

The average flow rates appeared to be approximately distributed within about 600pc/h to 1,000pc/h in the ramp influence areas. And the minimum and maximum flow rates (capacities) were expected to be within about 70pc/h to 170pc/h and about 1,100pc/h to 1,600pc/h in the ramp influence areas, respectively. Also, the flow rates in the daytime period from 07:00 to 20:00 appeared to be

approximately distributed within about 700pc/h to 1,400pc/h in the ramp influence area A, about 1,000pc/h to 1,400pc/h and about 700pc/h to 1,600pc/h in the ramp influence areas B and C, and about 700pc/h to 1,200pc/h in the ramp influence area D as shown in Table 3 and Figure 2. So, the flow rate distribution proved to be very effective in identifying the existence or nonexistence of a typical pattern at the peak periods in the ramp influence areas.

Table 3. Results of flow rate characteristic analysis

		Flow rate (pc/h)			
		Min	Max	Average	07:00～20:00
On-Ramp	A	112	1,354	668	1,200～1,400
	B	142	1,408	966	1,300～1,400
	C	142	1,562	995	1,400～1,600
	D	74	1,198	629	1,000～1,200
Off-Ramp	A	97	1,268	746	700～1,300
	B	112	1,337	880	1,000～1,400
	C	169	1,339	931	700～1,400
	D	139	1,157	811	700～1,200

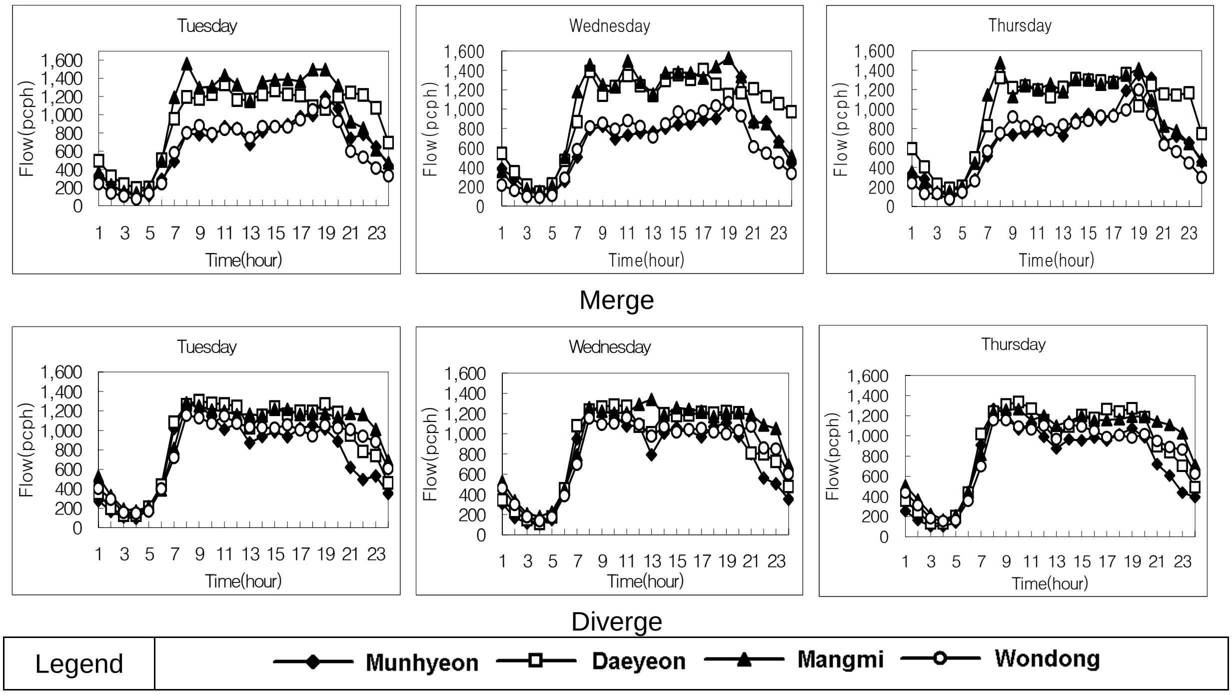


Figure 2. Flow rate distribution

2.2 Speed

Speed was expressed by a kilometer per hour (km/h) as the distance which the vehicles traveled for a unit period, and converted into the space mean speed (May, A. D., 1990, [4]) as shown in the below.

$$u_t = \frac{\sum n_i u_i}{\sum n_i}$$

$$u_s = \frac{\sum n_i}{\sum \frac{n_i}{u_i}}$$

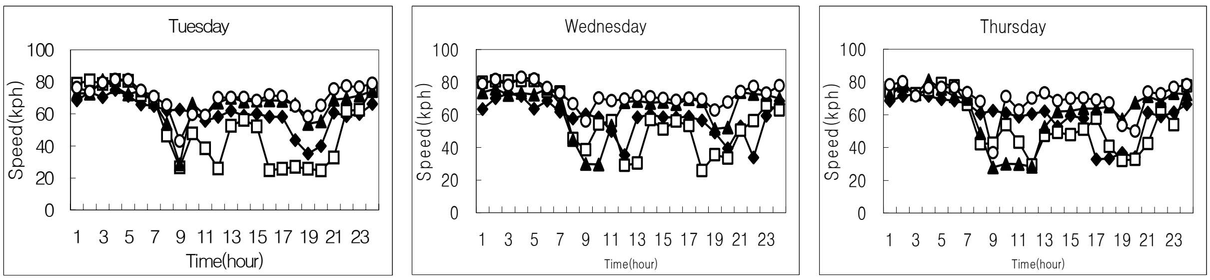
Where,

n_i	: No. of vehicle in the speed class (pc/15min)
$\sum n_i$	: No. of vehicle for every 15 minutes (N)
u_i	: Mean speed in the speed class (km/h)
u_s	: Space mean speed converted (km/h)
u_t	: Time mean speed observed (km/h)

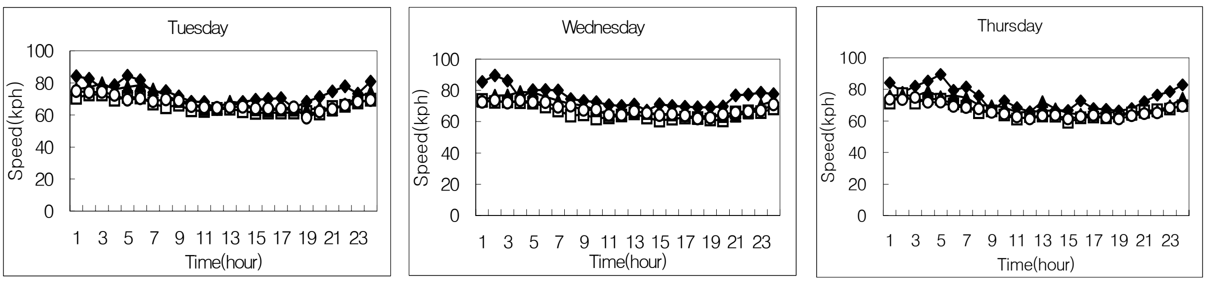
The average speeds appeared to be approximately distributed within about 50km/h to 75km/h in the ramp influence areas. And the minimum and maximum speeds were expected to be within about 20km/h to 65km/h and about 70km/h to 90km/h in the ramp influence areas, respectively. Also, the speeds in the daytime period from 07:00 to 20:00 appeared to be approximately distributed within about 25km/h to 80km/h in the ramp influence area A, about 20km/h to 75km/h in the ramp influence areas B, C, and D as shown in Table 4 and Figure 3. So, the speed distribution proved to be very effective in identifying the existence or nonexistence of delay at the peak periods in the ramp i nfluence areas.

Table 4. Results of speed characteristic analysis

		Speed (km/h)			
		Min	Max	Average	07:00~20:00
On-Ramp	A	32.8	75.0	59.0	25~35
	B	24.6	81.1	54.6	20~30
	C	27.9	81.1	63.8	20~30
	D	36.9	82.9	70.7	20~30
Off-Ramp	A	63.7	89.5	74.3	60~80
	B	59.2	77.3	66.0	55~70
	C	62.3	79.8	69.5	60~75
	D	58.2	74.9	67.1	55~70



Merge



Diverge

Legend	Munhyeon Daeyeon Mangmi Wondong

Figure 3. Speed distribution

2.3 Density

Density was expressed by a vehicle per kilometer (pc/km) as the number of vehicles which was traveling in the unit length of roadway, and estimated by the reciprocal of the headway distances (TRB, 1975, [2]) as shown in the below.

$$h = \frac{\sum (t_i - t_{n-1})}{\sum n_i}$$

$$k = \frac{3.6}{h_i \times u_{si}}$$

$$k_i = \frac{k_{U1} + k_{D1}}{2} \;,\; k_2 = \frac{k_{U2} + k_{D2}}{2}$$

$$D = \frac{k_1 + k_2 + k_3}{3}$$

Where,

h	: Mean headway for 15 min. (sec)
h_i	: Headway for every 15 min. (sec)
t_i	: Arrival time of vehicle i (sec)
t_{i-1}	: Arrival time of vehicle $i-1$ (sec)
u_{si}	: Space mean speed for every 15 min (km/h)
k_1	: Density of 1st lane from adjacent lane for 15 min (pc/15 min.)
k_2	: Density of 2nd lane from adjacent lane for 15 min (pc/15 min.)
k_3	: Density of adjacent lane for 15 min (pc/15 min.)
k_{U1}	: Density of upstream 1st lane for 15 min (pc/min.)
k_{U2}	: Density of upstream 2nd lane for 15 min (pc/min.)
k_{D1}	: Density of downstream 1st lane for 15 min (pc/min.)
k_{D2}	: Density of downstream 2nd lane for 15 min (pc/min.)
D	: Mean density in the merge and diverge influence area (pc/15 min.)

The average densities appeared to be approximately distributed within about 10pc/km to 25pc/km in the ramp influence areas. The minimum densities were expected to be within about 1pc/km to 2pc/km in the ramp influence areas. The maximum densities (jam densities) were also expected to be distributed within about 35pc/km to 55pc/km in the merge influence areas, and about 20pc/km to 30pc/km in the diverge influence areas. The densities from 07:00 to 09:00 appeared to be approximately distributed within about 30pc/km to 60pc/km in the merge influence area, about 10pc/km to 30pc/km in the diverge influence area, as shown in Table 5 and Figure 4. So, the density distribution proved to be very effective in identifying the existence or nonexistence of a jam at the peak periods in the ramp influence areas.

Table 5. Results of density characteristic analysis

		Density(pc/km)			
		Min	Max	Average	07:00~20:00
On-Ramp	A	2	38	17	30~40
	B	2	51	25	50~60
	C	2	54	18	50~60

	D	1	35	13	30~40
Off-Ramp	A	1	20	11	10~20
	B	2	22	14	10~25
	C	2	27	16	10~30
	D	2	30	14	10~30

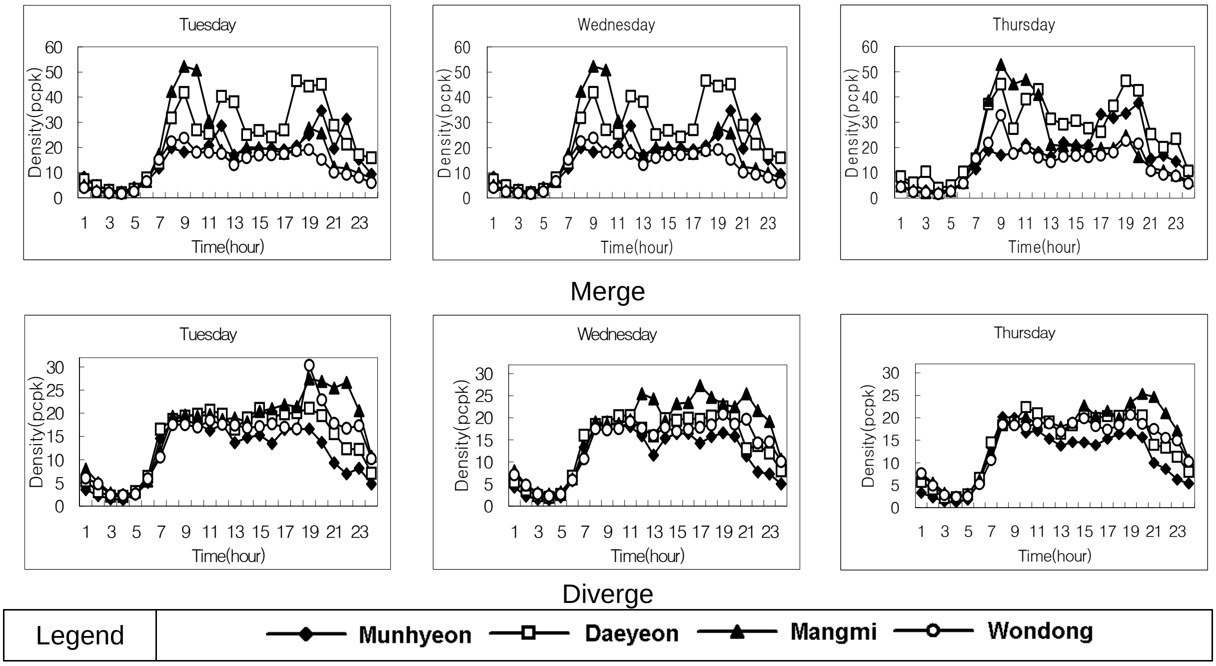


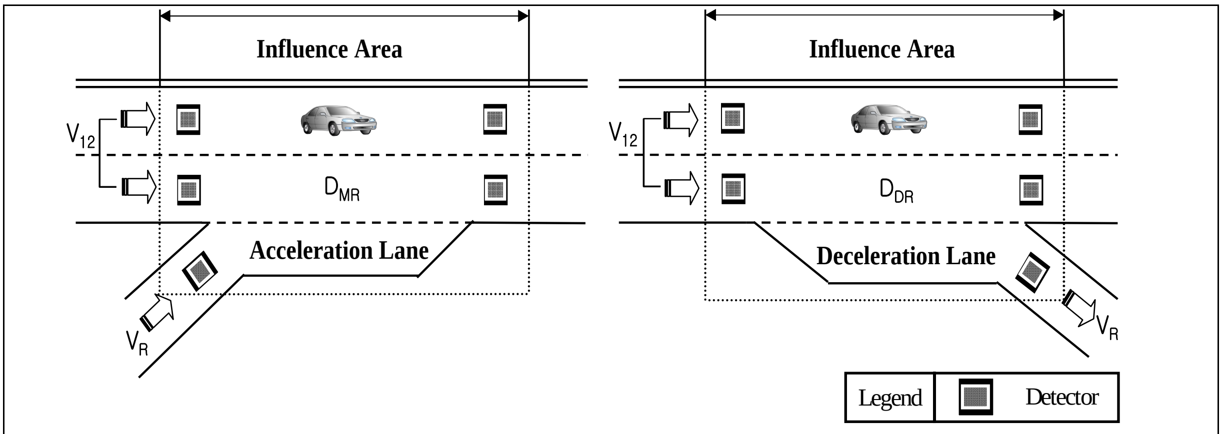
Figure 4. Speed distribution

3. Model development and Validation

The density predictive model was developed with a portion of traffic data collected in the ramp influence areas by using the multiple regression analysis, and validated by using the correlation analysis as well.

3.1 Model Development

In the density predictive model, ramp flow, flow of lane 1 and 2 from the adjacent lane, and length of change speed lane were used as the dependent variables, mean density in the ramp influence area as the independent one as shown in Figure 5;



Independent variables	
V_R	: Ramp flow (pc/h)

V_{12}	: Flow of lane 1 and 2 from adjacent lane (pc/h)
L_A	: Length of acceleration lane (m)
L_D	: Length of deceleration lane (m)
Dependent variables	
D_{MR}	: Mean density in the merge influence area (pc/km/l)
D_{DR}	: Mean density in the diverge influence area (pc/km/l)

Figure 5. Sketch of ramp junctions and definition of the variables

Under the assumption that the density in the ramp influence area would be influenced by the traffic and geometric characteristics in the ramp influence area, especially, ramp flow, flow of lane 1 and 2 from adjacent lane, length of acceleration and deceleration lanes, the density predictive model ($f(k)$) was suggested as follows;

$f(k) = \beta_0 + \beta_1 V_{12} + \beta_2 V_R + \beta_3 L_A$: Merge influence area

$f(k) = \beta_0 + \beta_1 V_{12} + \beta_2 L_D$: Diverge influence area

Where,

$\beta_0, ..., \beta_3$: Regression coefficients

The multiple regression analysis was used to build the density predictive model, which were developed by the all-possible-regression selection procedures for the purpose of identifying the important independent variables with the criteria of R^2. Particularly, the multi-collinearity was also avoided by the trial-and-error process.

Table 6. Result of density predictive modeling

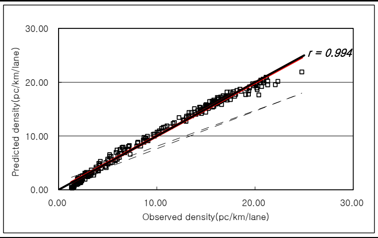
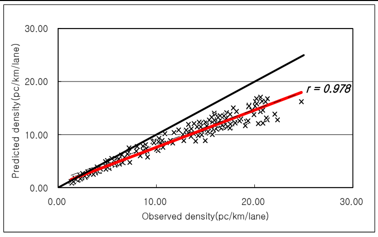
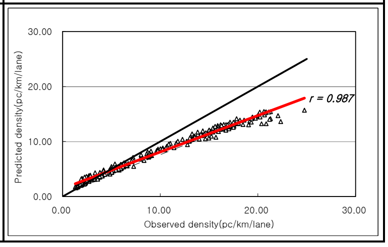
Model	R^2	$\Pr ob > F_{1)}$
$D_{MR} = 1.02644 + 0.005899 V_{12} + 0.009646 V_R - 0.010058 L_A$	0.986	0.000
$D_{DR} = 0.94158 + 0.006352 V_{12} - 0.007434 L_D$	0.931	0.000

Annotation 1) $(P > \lvert t \rvert) = (P - value)$

So, the density predictive model proved to be determined by ramp flow, flow of lane 1 and 2 from the adjacent lane, and length of the acceleration lane as shown in Table 6.

3.2 Model Validation

There were two approaches applied to ensure the validity of the models developed. One approach was to conduct t-test between the observed and expected densities, whether the p-values were greater than the significance level ($\alpha / 2 = 0.025$) or not at the 95% confidence level as shown in Table 7. They were fully less than the p-values in the ramp influence areas under the study. Another was to test the utility of the regression models with traffic data unused. The results (r) of the correlation analysis were shown to be 0.968 and 0.994 in the ramp influence areas regardless of the urban and suburban areas as shown in Figure 6. So, these models proved to be very effective in predicting densities in the ramp influence areas on the urban area.

	This model	KHCM model	HCM model
On-Ramp			

Off-Ramp

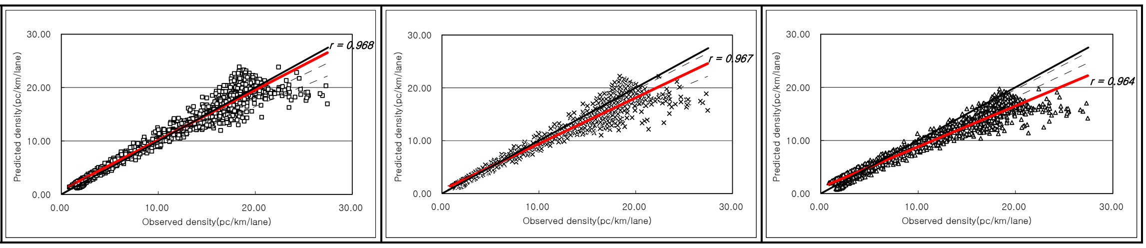


Figure 6. Correlations between the observed and expected densities

Table 7. Results of t-tests between the observed and expected densities

		t-value	p-value	Result
On-Ramp	KHCM	17.65133	0.000	Reject
	HCM	12.62977	0.000	Reject
	This Model	-0.75129	0453	Accept
Off-Ramp	KHCM	17.538	0.000	Reject
	HCM	28.474	0.000	Reject
	This Model	-0.004	0.997	Accept

4. Model Evaluation

The statistics were applied to evaluate the measures of effectiveness (MOE) between this model, the HCM model, and the KHCM model. The statistics applied were to compare the root mean square error (RMSE) between the observed and expected densities by the models.
Particularly, there was the more difference in root mean square error (RMSE) of this model (0.981~1.768) than those in the KHCM model (2.056~3.205) and the HCM model (2.813~2.861), respectively as shown in Table 8. So this model proved to have a higher predictability than the KHCM and HCM models in urban freeway ramp influence area.

Table 8. RMSE results of density models predicted

	This Model	KHCM Model	HCM Model
On-Ramp	0.981	3.205	2.861
Off-Ramp	1.768	2.056	2.813

5. Conclusions

From the traffic characteristic analyses, and the development and validation of the predictive density model in the ramp influence areas, the following conclusions were drawn;

ⅰ) Traffic characteristics distributed were shown to be very effective in identifying their distinct characteristics at the peak periods in the urban freeway ramp influence areas,

ⅱ) Daytime period from 7:00 to 20:00 has a higher density than the nighttime period regardless of the location or direction.

ⅲ) Density in the ramp influence area was shown to be highly correlated by the ramp flow (V_R), flow of lane 1 and 2 from adjacent lane (V_{12}), and length of speed change lane (L_A, L_D) and,

ⅳ Density predictive model were shown to be higher in the explanatory power (R^2) than the KHCM and HCM models with about 0.931~0.986 in the ramp influence areas under the study.

It was concluded that this study was needed to be continued under the various geometric characteristics for the purpose of the reliability of the density predictive model.

References

1. America Association of State Highway and Transportation Officials, A Policy on Geometric Design of Highways and Streets, AASHTO, Washington, D.C., 2004

2. Bowerman, B.L., and O' Connell, R.T., Linear Statistical Model; an applied approach , PWS-KENT Publishing Company(1990)

3. Gartner, N., Messer, C.J., and Rathi, A.K., Traffic Flow Theory; A Monograph, Special Report 165, Revised Edition, Transportation Research Board, National Research Council, Washington, D.C., 1997

4. Korea Ministry of Construction and Transportation, Korea Highway Capacity Manual, KHCM, Korea, 2005

5. Transportation Research Board, Highway Capacity Manual, National Research Council Washington, D.C., 2000